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PROGRAM MANAGEMENT COURSE
INDIVIDUAL STUDY PROGRAM

TRAINING DEVELOPMENTS:
A MEANS TO REDUCE LIFE CYCLE COSTS?

STUDY PROJECT REPORT

PMC 77-1

TROY VERNON CAVER
MAJOR USA

FORT BELVOIR, VIRGINIA 22060

TRAINING DEVELOPMENTS: A MEANS TO REDUCE LIFE CYCLE COSTS?

Individual Study Program

Study Project Report

Prepared as a Formal Report

DEFENSE SYSTEMS MANAGEMENT COLLEGE

PROGRAM MANAGEMENT COURSE

CLASS 77-1

by

Troy V. Caver
Major USA

May 1977

Study Project Advisor
LTC Joseph Arcieri, USAF

This study project report represents the views, conclusions and recommendations of the author and does not necessarily reflect the official opinion of the Defense Systems Management College or the Department of Defense.

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DEFENSE SYSTEMS MANAGEMENT COLLEGE

STUDY TITLE:

TRAINING DEVELOPMENTS: A MEANS TO REDUCE LIFE CYCLE COSTS?

STUDY PROJECT GOALS:

To determine if training developments can be considered along with hardware developments in trade-off analysis to achieve lower life cycle costs and if so, how?

STUDY REPORT ABSTRACT: This report examines new training concepts developed throughout DOD over the past decade. The concepts that show promise for reducing life cycle costs are considered for trade-offs with hardware developments. The process of trade-off considerations is treated with a marginal cost-marginal benefit analysis (put the investment where it provides the biggest return). The writer then conducts a sensitivity analysis on parameters affected by training using a computer model to determine a trend in life cycle costs/savings. The writer concludes that many benefits can be derived by increasing the share of the investment in the training subsystem although it may be at the cost of the hardware subsystem in some cases. These investments appear to be best placed in training and technical documentation or in job performance aids. He concludes that not only should this type investment reduce the life cycle cost but also provide job enrichment, higher operational availability, fewer maintenance personnel requirements, fewer training course requirements, increased systems effectiveness, and other savings.

The implication of the study is that Project Management personnel concentrate on the hardware aspects of a developing system while investments in training developments provide a greater return on the later investment and would yield greater user satisfaction.

Subject Descriptors:

Training Developments
Technical Documentation
Job Performance Aids
Life Cycle Costs
Life Cycle Savings
Life Cycle Cost Models
Trade Off Analysis

NAME, RANK, SERVICE	CLASS	DATE
TROY V. CAVER, MAJOR, USA	PMC 77-1	May 1977

EXECUTIVE SUMMARY

This study project examines the benefits of recent Training Developments which are the results of integrating technical documentation and training techniques into a composite package. It also examines the results of Training Development studies conducted in all three US Services. It includes insights into the problems of achieving expected operational availability, maintainability, and lower Life Cycle Costs for new systems, that is the total cost related to a system over its life such as research and development, procurement, operations and support, and salvage. The maintenance documentation concepts are examined illustrating the interrelationships of technical and training documentation with systems maintainability. The implications of using documentation concepts tailored for specific equipment types were investigated with the expected results recorded herein. Representative findings from the studies, tests, and experiments examined were used as computer data changes to a life cycle cost model with the computed results included in this report. These results were examined in light of recent DoD guidance to reduce Life Cycle Costs. It is concluded that the proper selection of promising training development concepts such as technical and training documentation will reduce life cycle costs and increase operational availability. Other more specific expectations are reduced personnel requirements, reductions in training time, decreased mean time to repair, fewer job specialties, reduction in

spare parts usage, greater user satisfaction, and a more usable support package for foreign military sales.

It is further concluded that an overall systems effectiveness approach is required to give sufficient emphasis to training and support and insure project managers plan and contractually support the selection and development of the most effective materials.

It is also concluded that revision of existing technical and training documentation may be a viable alternative to upgrading system performance and may be more cost effective than the customary hardware modifications of Product Improvement Programs (PIP).

The implication of the study is that present practices emphasize inherent hardware reliability and availability values while ignoring enhancement through improved training developments, a relatively simple means of receiving greater payoffs and increased user satisfaction while reducing life cycle costs.

ACKNOWLEDGEMENT

The author is grateful to Dr. Edgar L. Shriver, President of Kinton, Incorporated, Alexandria, Virginia, for providing his time during interviews, his insights into the problems studied and a wealth of published information concerning the topic.

The author also expresses his gratitude to Air Force Lieutenant Colonel Joseph Arcieri for his guidance and review and to the many other professionals who gave of their time and experience in assisting to round off the rough edges.

PREFACE

This study was undertaken because the author, while a member of the Army Combat Development efforts in Training and Doctrine Command (TRADOC) over the past six years, has seen increased adversary relations develop in the Army between the developer and user. During that time, while working as an Operations Research Systems Analyst, he observed that the system values achieved by the developer in response to the requirements document (such as operational reliability, availability, and maintainability) were in fact closer to inherent (or hardware) values and were never or rarely the values achieved either in user tests during development or after fielding. It was apparent to the author that failure to consider the man interface was a primary reason for the degraded performance.

The author was instrumental in developing much of the Army Systems Acquisition user test policy from 1974 - 1976. He also attended during that period numerous meetings between developer and user commands where test failures, failure definitions and scoring criteria, training and logistics shortcomings and overall systems effectiveness were related and discussed for resolution. With this background and the knowledge that many studies, tests, and experiments related to training and technical documentation developments had been conducted with cost saving recommendations, this task was undertaken. The test and study results also hinted at a

method to improve the military readiness levels with a reduction in life cycle costs while increasing user satisfaction and equipment utility/desirability.

TABLE OF CONTENTS

SECTION I

INTRODUCTION

The job of maintaining a military force in a high state of readiness falls on the military commander. On the modern battlefield he is going to be equipped with sophisticated weapons and support equipment more complex than ever before. He has a major task of maintaining those weapons in a high state of readiness and to employ them in their mission whenever required to enter the battle. However, for years reports from users throughout the world have expressed concern and great difficulty in maintaining the readiness conditions required. Many factors have been given as contributing causes such as lack of repair parts, high equipment failure rates, long times to repair, and inadequately trained maintenance personnel. Our servicemen and the country deserve equipment that once employed in battle can be expected to remain operational for the duration of the mission. Any system found to be non-operable should be expected to be brought back to an operable condition in the minimum amount of time.

In a statement to the 94th Congress Second Session 3 Feb 1976 concerning DoD Research, Development, Test and Evaluation Program, Dr. Malcolm Currie stated:

> "At present, while the development and procurement costs of DoD systems and equipment are well identified, our understanding of the real life cycle costs are sketchy at best, because of the way DoD operation and support costs are reported.

Because knowledge of total Life Cycle Costs is vital to decision-making, OSD has expanded its effort to improve visibility of operating and support costs, so that all cost drivers can be identified and timely efforts to reduce them initiated...."

"Since reliability, maintainability, and direct personnel costs influence operating and support costs, the DSARC has been imposing more stringent requirements for reporting actual field reliability and maintainability achievements and related support costs throughout the life of each program. This action will focus increased management attention on these elements of life cycle costs...."

Lieutenant General George Sammet, Jr., Deputy Commanding General for Materiel Development, Army Materiel Development and Readiness Command, speaking at the American Defense Preparedness Association Tank Automotive Division Meeting in Monterey, California, 17 Nov 76 stated:

"...Right along with reliability goes maintainability. I don't care how reliable a vehicle you put in the field, sooner or later it's going to break down and need fixing. The easier and faster it is to do that job, the more ready we will be.

Along with good maintenance is good technical data. If you are going to tune up your Ford you can't use a Jaguar manual to tell you how to do it. Using some of our manuals in thepast was about like using a Jaguar manual to fix a Ford. Our old manuals were difficult to read, or there were no illustrations, or the illustrations were all wrong - or at least wrongly placed in the manual. Some are still that way. But we are correcting this situation. We have to, if we are truly going to have equipment readiness.

If a soldier is going to maintain his equipment, the soldier is going to have to be able to troubleshoot it. To troubleshoot it he's going to need test and support equipment. Too many times in the past we've fielded a new piece of equipment long before the less glamorous test and support equipment was ready."

Later he also stated:

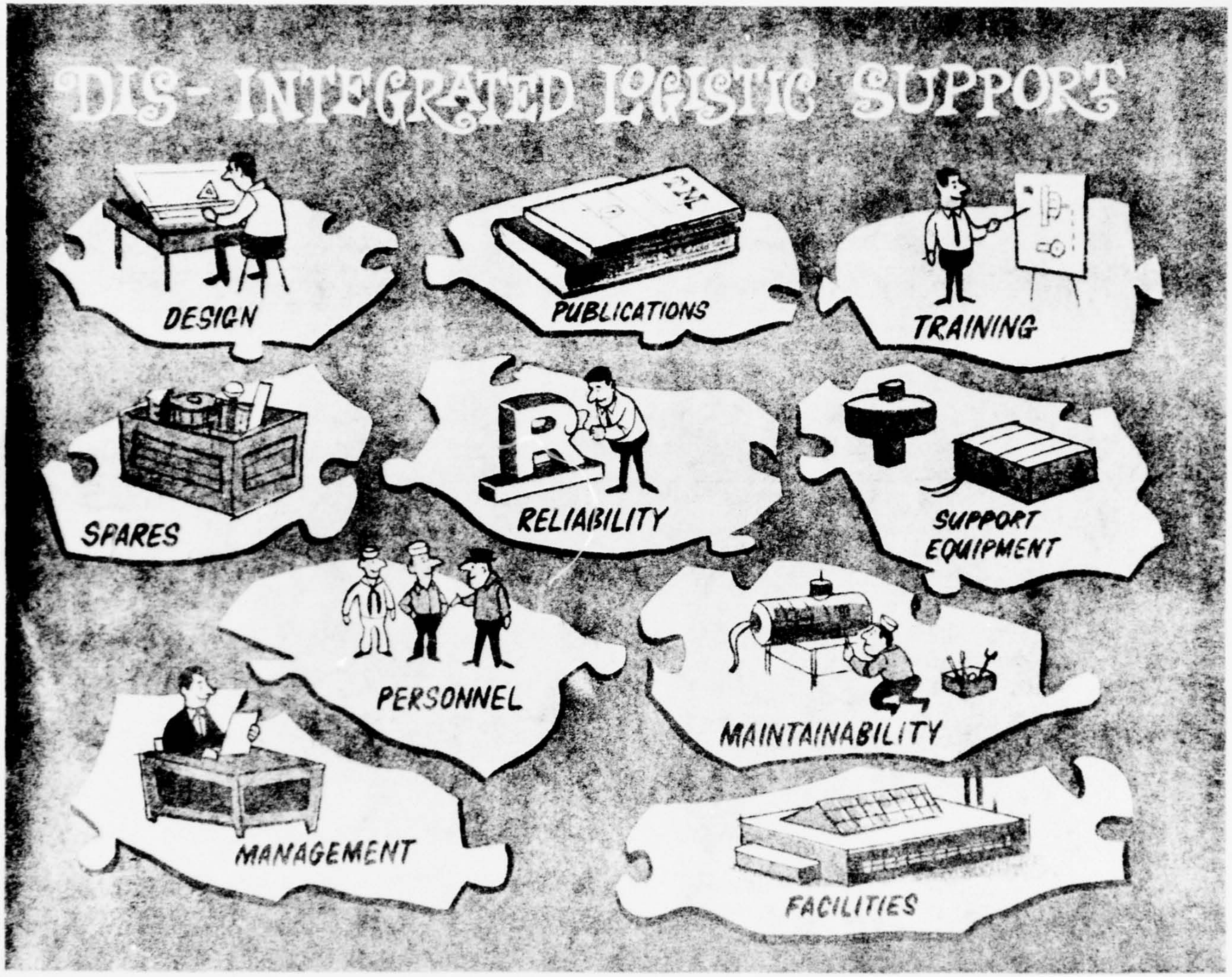
> "You can't put reliability in a vehicle after it's in the field. ...Reliability has to be built into a vehicle, and its not going to get there by accident.
>
> The same goes for Tech (technical) Manuals. They don't write themselves, yet manuals are as much a part of readiness as the mechanics tool kit...."

Also, while discussing support cost and Design to Unit Production Cost (DTUPC) he stated:

> "Our critics argue that we should have been talking DTUPC and life cycle costing all the time. Since the life cycle cost is a lot tougher number to predict, we did push it into the background. Well, its time has come - as they say on TV - to get the whole package under a life cycle cost figure."

Over the past ten years, DoD has put much emphasis on improving the maintenance of the hardware by emphasizing reliability and maintainability as design criteria and the development of automatic and built-in test equipment. Very little attention, however, has gone into improving the maintenance information. The conventional technical manual system has existed without change for decades. Some gradual improvement has occurred but there has been no innovative thrust to improve the effectiveness of the people portion of our maintenance system. Some examples of these technical manual problems and possible solutions are at Figures III-1 and III-2. Also, as stated by Dr. Currie later in his referenced presentation, approximately 25% of all military personnel are employed in full time maintenance service. This does not include operators of trucks, tanks, guns, etc. If we consider the individual cost at $20,000 per man year (a

low estimate) this represents $10 billion per year (this figure varies with total DoD strength,currently 2.1M). If we then inject that one-fourth of these men are new to the service each year and that training costs about $1,000 per week, with the service school technical course averaging 20 weeks to get them ready for work (with no useful output during training) that adds $2.4 billion per year[1:50]. The DoD maintenance personnel support is easily in excess of $12.4 billion per year. The primary purpose for stating these facts is to put emphasis on the publications, training and personnel systems - three of the many dis-integrated[3] elements, reference figure I-1, of systems under development, each of which should integrate and improve system effectiveness by better training developments. Within the DoD community many experiments and demonstrations have shown that improvements to technical manuals and other new ways of presenting information may enable technicians to perform faster and more accurately, and with less training. These techniques have the potential of reducing the cost of maintenance and maintenance support (training) by 25-50% and at the same time improve the equipment availability. Two studies conducted for DoD elements in recent years were relied on heavily for this paper[1,2]. Each of them reviewed and reported the many techniques and concepts used in improving training and maintenance. This paper will present the results of many of these examinations, discuss the applications and recommend several steps that DoD should take in implementing the results.



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DSMC

Figure I-1

PURPOSE OF THE STUDY PROJECT

It is the purpose of this study project to examine the results of studies and experiments concerning new training development concepts (Section III) and to consider the influence on System Life Cycle Costs when applying these new concepts.

SPECIAL GOALS OF THIS PROJECT

The goal of this project is to answer the following question: Can training and technical documentation developments be incorporated into trade-off considerations with hardware developments for achieving lower life cycle costs and if so, how?

LIMITATIONS OF THE STUDY

The limitations of time and resource material were the primary limiting factors. During the data gathering phase it was desirable but not practical due to limited time to visit existing program management offices to develop more information on problems of implementation and interface. Also due to time it was not possible to obtain data from the many industry organizations or professional societies that have worked on this subject.

SIGNIFICANCE OF THE STUDY

Many Department of Defense Directives and Instructions have been published stating Life Cycle Cost will be used as a constraint in System Acquisition. Other documents have stated the importance of user involvement.

However, the primary emphasis of program managers and the system acquisition process continues to be hardware development and acquisition. While it is obvious that the primary element of the system initially is the hardware, and the early concern is in hardware development, it is not at all clear to this writer why the 'hardware fascination' continues throughout the acquisition process at the expense of the other system elements. If the many results of this study are recognized by DoD policy makers as worthwhile, the 'hardware acquisition process' will become the 'system acquisition process' in fact and not just in print. The benefits of such a change are obvious as hardware is only one of the many subsystems of the total system.

ORGANIZATION OF THE STUDY

The study is organized into sections. The first introduces the study with its purpose, goals, limitations, significance, and organization. The second section discusses the meaning of training development and other related support terms. The third section presents the results of many studies, tests, and experiments that have been undertaken to examine new concepts of training and technical documentation developments. The fourth section translates the findings of section three into usable information for decision making. Trade off analyses are considered by modeling for Life Cycle Costs, considering marginal cost and marginal profit analysis, and examining cost drivers. Section five presents conclusions, recommendations and implications of the study project.

SECTION II

TRAINING DEVELOPMENTS AND OTHER RELATED SUPPORT DEFINITIONS

The purpose of this section is to examine the meaning of training developments and related terms such as Job Performance Aids, technical data, and maintainability as used in this study.

TRAINING DEVELOPMENT

Training development as evolving throughout DoD[4:33] integrates technical documentation and training into a composite package which provides a reference state of all information needed to operate and maintain an equipment system. The technical documentation contains fully detailed, illustrated instructions which enable novice technicians to perform complex tasks with little or no training. The training materials consist of self study lessons which teach the preliminary skills necessary to use the documentation in operating and maintaining the equipment. For either existing or evolving tasks, a developmental program to accomplish these new goals is to take a macrocosmic view of the system/problem and bring together the Job Performance Aids (JPA) approach to data presentation and training.

JOB PERFORMANCE AIDS

Job Performance Aids may be booklets or viewing devices which present step-by-step procedures with simple illustrations supported by easy to read

text. They present the soldier with technical data in an illustrated, easy-to-read, step-by-step format supported by a training package which integrates the necessary material to teach critical tasks, frequently recurring tasks, and procedures relative to troubleshooting, safety, and emergencies. Key features of the new training development concepts are that[(4:34)]:

- Development is based on an analysis of job and task requirements.
- Material is developed with the target audience and work conditions in mind.
- Technical data is presented in job sequence and organized for accessibility (figure II-1).
- Training and Technical Documentation are integrated.
- Technical manuals and training packages are verified by users under realistic conditions prior to acceptance.

Man's limitations and capabilities must be considered early in the hardware design and then personnel must be trained to the skill level required to operate, maintain, and support systems and equipment for ultimate effectiveness. They can do this only with proper technical data.

TECHNICAL DATA

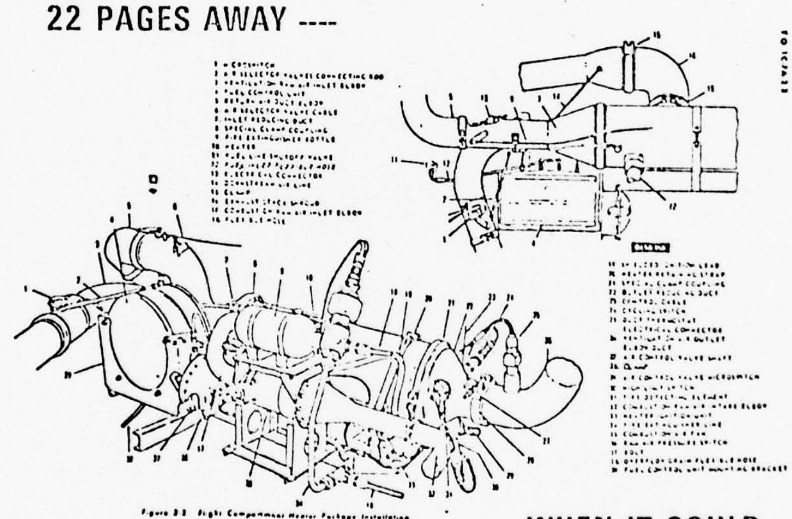
Technical data provides the link between the man and the machine, the maintenance technician and the part, the driver and his tank. Technical data are written instructions such as drawings; operating, maintenance, and modification manuals, specifications, inspection test, and calibration procedures; and computer programs required to guide people performing operations and support tasks. An example of technical data are technical

WHEN IT SAYS...

2. DISCONNECT AIR SELECTOR VALVE CABLE (6. FIGURE 2-2) FROM AIR SELECTOR VALVE PIVOT SHAFT LEVER ON TOP OF INLET REDUCING DUCT BY REMOVING COTTFR PIN, WASHER, AND FLAT HEAD PIN SECURING CABLE FORK END TO LEVER.

AND SHOWS ...

22 PAGES AWAY ----

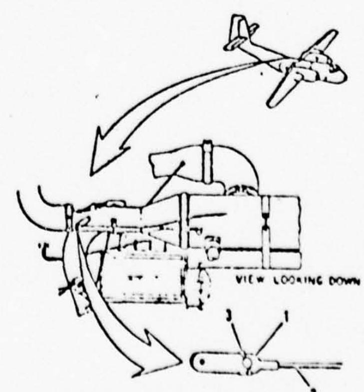


WHEN IT COULD ----

SAY...

DISCONNECT CABLE (2)
BY REMOVING KEY (3)
AND PIN (1).

AND SHOW...



ON THE FACING PAGE!

Figure II-1

orders giving instructions on how to repair equipment. Delivery of technical data at the same time the corresponding hardware is delivered is an important objective of the Project Manager. It is difficult and impractical to maintain or operate much of the complex equipment now being produced without clear and simple written guidance. Thus the scheduling of technical data developments and distribution must mesh with equipment production schedules.

MAINTAINABILITY

Maintainability is a design characteristic which is expressed as the probability that an item will be retained in, or restored to, a specified condition within a given time period when maintenance action is performed according to the prescribed procedures. A parameter often used as an expression of maintainability is mean time to repair (MTTR). Maintainability is a quantitative characteristic that can be predicted in design, controlled in production, measured by test, and maintained in the field.

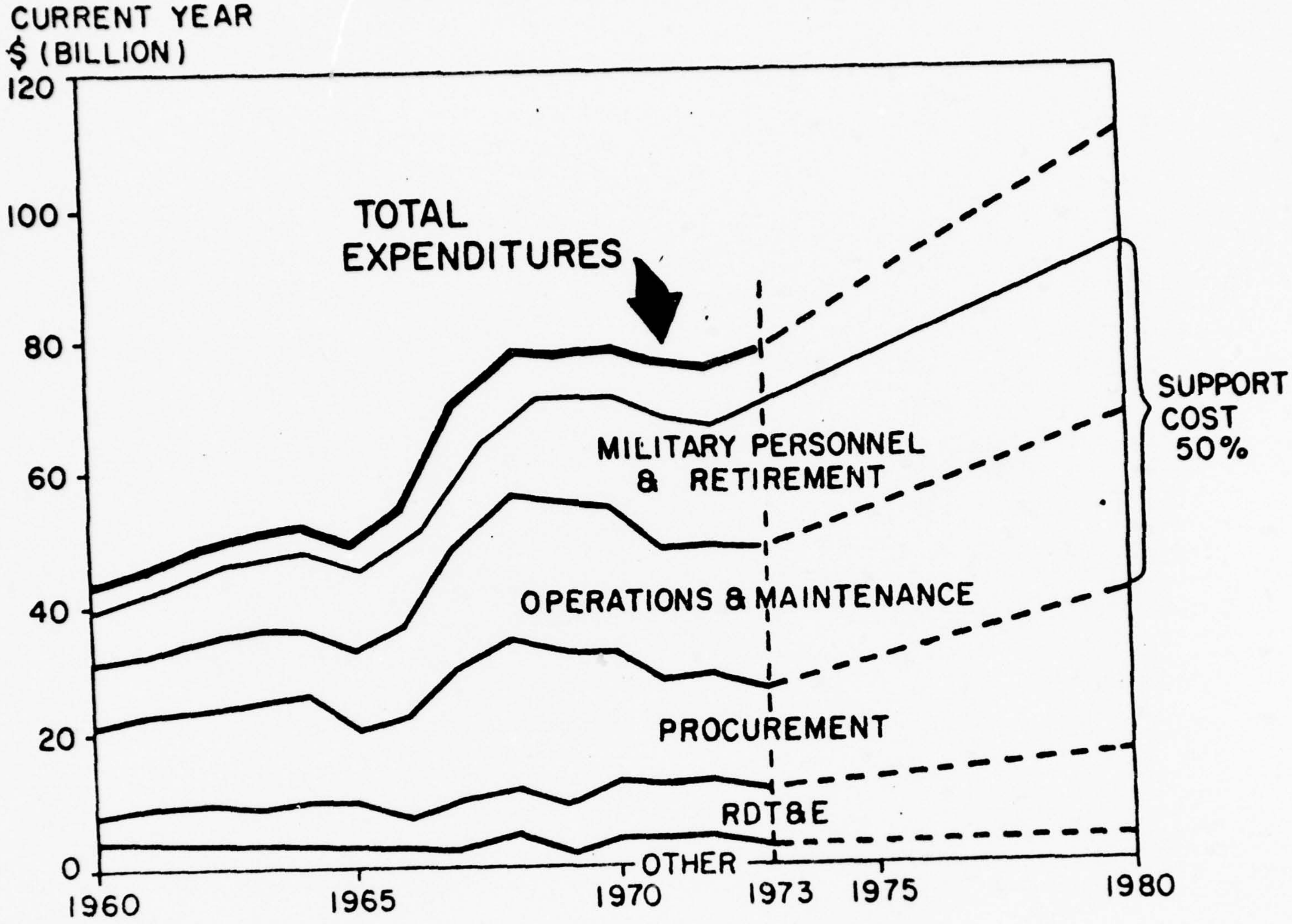
A Reminder

Maintainability is the ability of the item to be maintained whereas maintenance is a series of actions to restore or retain the item in the specified condition.

The maintainability characteristic of hardware dominates the number and types of trained personnel, tools, equipment, spare parts, and technical data for support of the equipment in an operational environment.

Maintenance, operations, and personnel costs as shown on the following graph[5] account for an estimated 50% of a systems total life cycle costs and are projected to account for this portion in the future (reference figure II-2).

REDUCE SUPPORT COSTS



DSMC, SELM, Class Handout LTC Arcieri

Figure II-2

SECTION III

RESULTS OF STUDIES EXAMINING NEW CONCEPTS IN TRAINING AND DOCUMENTATION

The purpose of this section is to present the results of the many studies, tests, and experiments conducted to develop improvements in the military training and technical documentation.

There have been approximately eighty 'new concepts' such as the 'before' and 'after' extracts on the following pages, designed or developed to make improvements on the performance of the personnel, primarily through improved manuals[2:12]. The studies examining the change of content and technical information format show some surprising things. For example, 25 research reports on some 30 new concepts report improvements in job performance or reduction of training time when manuals incorporating the new concepts were used. These study reports were examined with the following two questions in mind:

1. How are the research results converted into lowering the cost of ownership, and
2. What are the fundamental processes that make these new concepts so effective?

The examinations revealed that improvements must come from one of these:

1. Reduced training time.
2. Reduced number of personnel required to do the job. (Increased proficiency of individual men.)
3. Reduced errors (reduction of false removals improved by increased proficiency).

Type of Literature: TECHNICAL
Reading Problems:
HARD WORDS
TOO WORDY
WEAK VISUAL AIDS
words/Total: 384/631-61%
FORCAST Reading Grade Level Score: 10.8

CHAPTER 3

ROCKET AMMUNITION

15 Technical Characteristics

a. Nose Cap Assembly. The nose cap assembly (fig 8) contains the piezo-electric element which is crushed on impact with the target. When the piezoelectric element is crushed, a small amount of electric energy is developed and transmitted through the lead wire to the fuze. This current initiates the firing train starting at the electrical detonator.

b. Rocket Motor Ignition System. The rocket motor ignition system (fig 9) for the M72A1/M72A1E1 is composed of the following elements: firing pin housing, firing pin rod and firing pin rod spring, M29A1 percussion primer, primer block with black powder flash charge, flash tube, and black powder igniter. The following sequence takes place as the unit is cocked and fired: The firing pin rod spring is compressed as the inner tube is extended and locked into position (fig 9). When the trigger is actuated the firing pin rod is released and strikes the center of the M29A1 primer with sufficient force to detonate the primer. The flash from the primer ignites the flash charge located directly behind the primer in the primer block. The ignited black powder generates a flash or flame which travels within the plastic flash tube to the igniter. The flame is dispersed within the igniter body through radial holes in the flash tube extension, igniting the black powder charge in the igniter. The thin plastic film which seals the front surface of the igniter is burned away, allowing the flame front to progress to the propellant and ignite it. The igniter remains in the rocket nozzle until the pressure reaches several hundred pounds per square inch. This pressure level assures that the propellant is ignited and that combustion is [illegible] the igniter body, and the rocket will start to accelerate. The time required for this sequence of events is about 40 milliseconds between the time the trigger is squeezed and the launching of the rocket. (For the M72A1 and M72A1E1, the firing pin rod assembly functions the same as the firing pin cable and the firing pin on the M72.)

c. Rocket Propulsion. The rocket is propelled by a discharging jet of hot gas generated by the burning propellant. The basic principle of rocket propulsion may be described as follows. In the case of a rocket motor, the gas pressure is built up by the burning propellant inside the motor. When an opening is made at one end of the chamber the pressure at the open end drops to near atmospheric level while the pressure on the closed end of surface remains momentarily much greater than the normal atmospheric pressure. As a result of this unbalanced pressure within the rocket motor the rocket starts to move in the direction of the closed end as a stream or jet of gas is exhausted from the open end or nozzle. The speed and the quantity of the gases escaping to the rear determine the speed of the rocket. Pressure within the

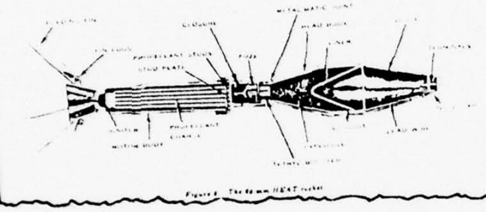


Figure 8. The 66-mm HEAT rocket

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rocket motor will be maintained until the propellant is completely burned and, therefore, the rocket will accelerate until the burning of the propellant is completed. The total burning time is controlled by the propellant type and size.

d. Fuze. The M412 fuze is drop-safe and bore-safe. The minimum arming distance is approximately 30 feet. For graze functioning of the fuze, there is a spring-loaded firing pin which is released by decelerating force of graze impact. This fires a stab sensitive primer located adjacent to the detonator. This action in turn [illegible] the explosive train [illegible].

e. Fin Assembly. [illegible] for attachment lugs are attached as an integral part of the motor. These fins are actuated by springs. As the rocket clears the launcher, the fins spring out and stabilize the rocket in flight (fig 8).

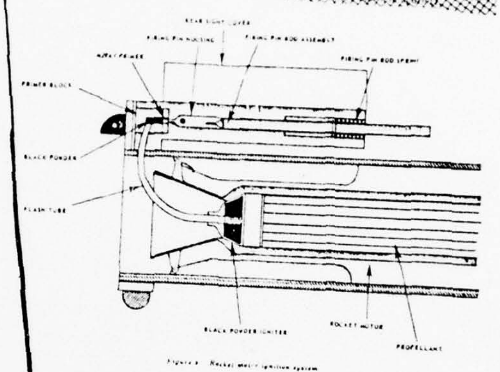


Figure 9. Rocket motor ignition system

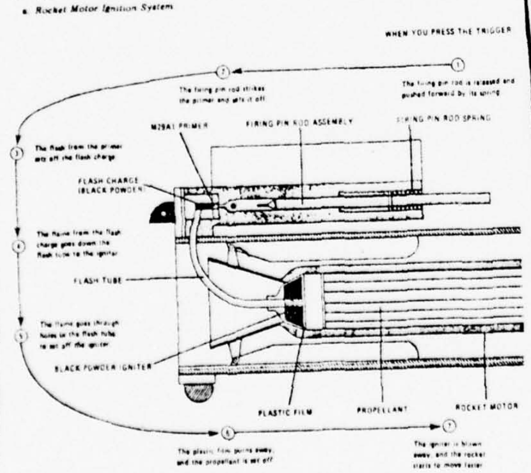
BEFORE

CHAPTER 3

ROCKET AMMUNITION

15 TECHNICAL CONSIDERATIONS

a. Rocket Motor Ignition System



b. Rocket Propulsion. As the Propellant burns, it gives off a jet of hot gas. It is this gas that pushes the rocket forward. The way the gas works is simple.

(1) The propellant is inside the motor. As the propellant burns, it fills the motor case with gas under pressure.

Type of Literature: INFANTRY TECHNICAL
Primary User: WORKER
Information Objectives: HOW IT DOES IT
No. of 1 Syll. words/Total No. words: 207/288-72%
FORCAST Reading Grade Level Score: 9.2

(2) When the igniter blows away it leaves a hole in one end of the motor case.

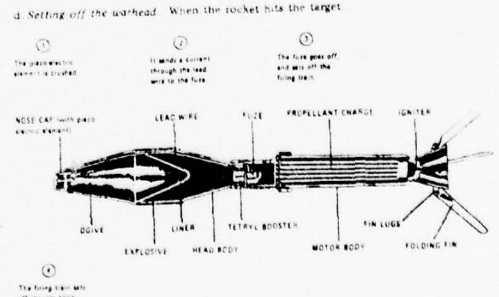
(3) The gas pressure on the open end of the case drops to the same pressure as the air outside the case. The pressure on the closed end is much higher than that on the open end.

(4) The pressure starts to even out inside the case as a jet of gas leaves the open end. This jet pushes the rocket forward. The amount and speed of the gas jet control the speed of the rocket.

(5) As the propellant continues to burn and give off gas, the pressure inside the rockets motor stays uneven. The rocket goes faster and faster until the propellant is all burned. The total burning time depends on the size and type of propellant.

c. Fins. Six fin lugs attach six folding fins to the motor case. When the rocket clears the launcher, springs push the fins out into place. The fins steady the rocket, and keep it from spinning in flight.

d. Setting off the warhead. When the rocket hits the target



e. Fuse. The M412 fuse is drop-safe and bore-safe. It has an arming distance of 30 feet or more. In a direct hit, the piezo-electric element in the nose cap sets off the fuse. In grazing fire, the glancing impact against the ground or objects slows down the rocket. A spring-loaded firing pin senses this, and sets off a stab sensitive primer near the detonator. This sets off the explosive train.

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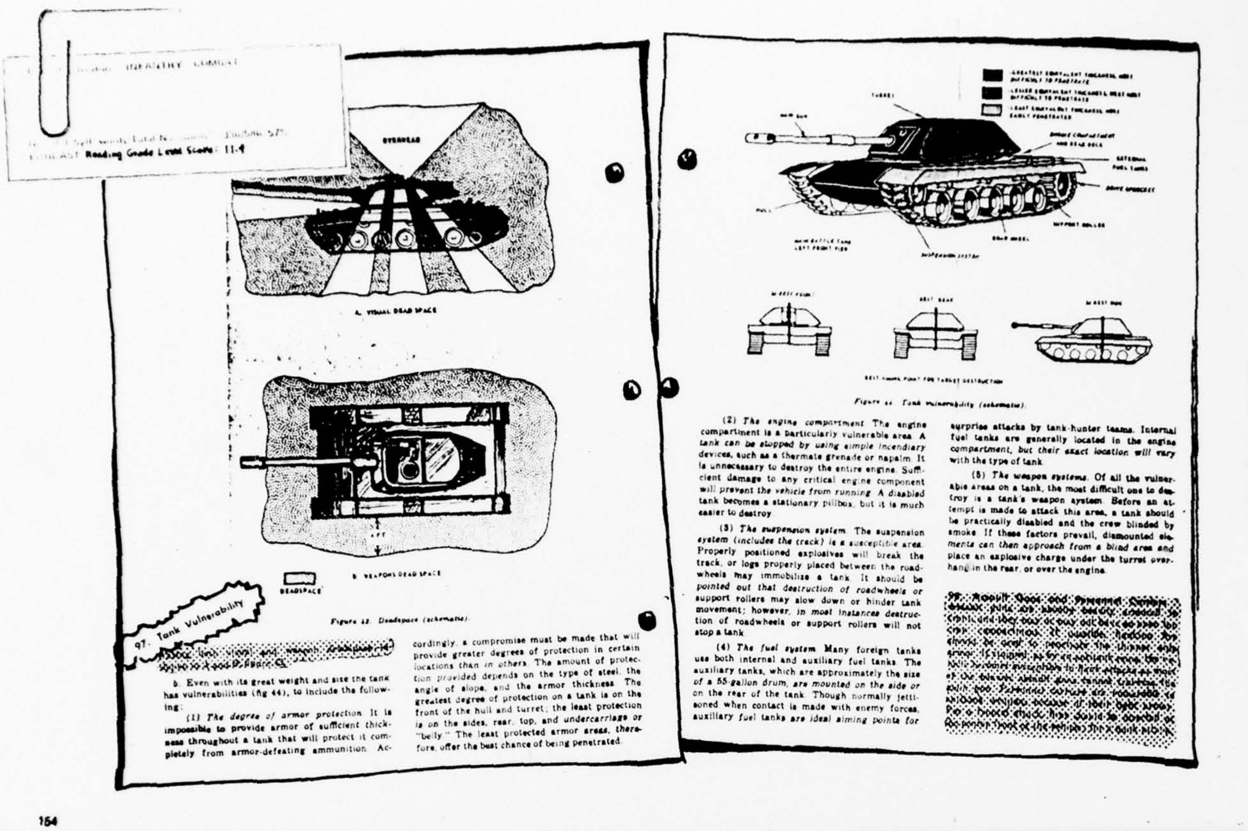
AFTER

Figure III - 1
Example of Change to a Technical Manual



FORCAST Reading Grade Level Score: 11.9

OVERHEAD

A. VISUAL DEAD SPACE

B. WEAPONS DEAD SPACE

DEADSPACE

Figure 43. Deadspace (schematic).

97. Tank Vulnerability

b. Even with its great weight and size the tank has vulnerabilities (fig 44), to include the following:

(1) *The degree of armor protection.* It is impossible to provide armor of sufficient thickness throughout a tank that will protect it completely from armor-defeating ammunition. Accordingly, a compromise must be made that will provide greater degrees of protection in certain locations than in others. The amount of protection provided depends on the type of steel, the angle of slope, and the armor thickness. The greatest degree of protection on a tank is on the front of the hull and turret; the least protection is on the sides, rear, top, and undercarriage or "belly." The least protected armor areas, therefore, offer the best chance of being penetrated.

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Figure 44. Tank vulnerability (schematic).

(2) *The engine compartment.* The engine compartment is a particularly vulnerable area. A tank can be stopped by using simple incendiary devices, such as a thermate grenade or napalm. It is unnecessary to destroy the entire engine. Sufficient damage to any critical engine component will prevent the vehicle from running. A disabled tank becomes a stationary pillbox, but it is much easier to destroy.

(3) *The suspension system.* The suspension system (includes the track) is a susceptible area. Properly positioned explosives will break the track, or logs properly placed between the roadwheels may immobilize a tank. It should be pointed out that destruction of roadwheels or support rollers may slow down or hinder tank movement; however, in most instances destruction of roadwheels or support rollers will not stop a tank.

(4) *The fuel system.* Many foreign tanks use both internal and auxiliary fuel tanks. The auxiliary tanks, which are approximately the size of a 55-gallon drum, are mounted on the side or on the rear of the tank. Though normally jettisoned when contact is made with enemy forces, auxiliary fuel tanks are ideal aiming points for surprise attacks by tank-hunter teams. Internal fuel tanks are generally located in the engine compartment, but their exact location will vary with the type of tank.

(5) *The weapon systems.* Of all the vulnerable areas on a tank, the most difficult one to destroy is a tank's weapon system. Before an attempt is made to attack this area, a tank should be practically disabled and the crew blinded by smoke. If these factors prevail, dismounted elements can then approach from a blind area and place an explosive charge under the turret overhang in the rear, or over the engine.

BEFORE

AFTER

Figure III - 2
Example of Change to a Training Manual

The conditions for most studies were essentially those that exist on the job. In some cases the maintenance that was performed occurred in response to actual schedules and actual malfunctions. In other cases time was 'compressed' and maintenance personnel responded to equipment malfunctions that were introduced by the experimenters. In any case the test malfunctions were not selected as the ones that special manuals/techniques were designed to find. The special manuals were designed to treat any problem in maintenance of the hardware system. Thousands of maintenance problems in perhaps a hundred different hardware systems are represented in all of the research tests surveyed. The studies, tests, and experiments were conducted in all three services and the Coast Guard over a period of 15 years. The following reduction estimates were made by both Shriver(1:4) and Rowan(2:2), two years apart looking at similar but not identical data (Table III-1)(12:154):

- o Reduction in training of 75%
- o Reduction in work force of 15%
- o Reduction in false removals of 15%

The results clearly indicate that improvements in the maintenance personnel effectiveness are possible with potential of high cost savings.

Rowan's findings also included(2:2) *that these reductions could be* achieved at a cost within 20-25% of the cost now being expended for conventional technical manuals. If only one study revealed significant results, the reader may be tempted to say it was a coincidence. But there have been more than twenty-five studies in DoD and industry. They all point in the

same direction. Before going on the reader should be aware of the traditional assumptions about recording or passing technical information. They are:

1. Technical training is needed to provide the general theoretical thesis of the subject matter (electronics, mechanical, hydraulics, etc.).

2. Technical manuals should describe the specifics of the system to be maintained.

3. The maintenance man can and will combine 1 and 2 on the job to determine what should be done in each situation as it arises.

The assumptions common to the new concepts are that experts can analyze the equipment, determine what should be done to it in every possible situation, and record this in technical manuals so that even a novice can use it to perform the task correctly. Although the documentation technique for troubleshooting tasks was slightly different than those for non-troubleshooting, the trend and results were the same. Using the new kinds of documentation (Figures III-1,2), personnel with half as much training as groups using standard technical manuals, were able to correct three times as many malfunctions per unit time in a major radar system [2:10]. All the concepts are directed at telling the man <u>what</u> to do instead of teaching him about the system details and training in what is basically design engineering information. It emphasizes <u>training</u> and not <u>teaching</u>. The new types of documentations provide a more intelligible product. Intelligibility is enhanced by:

1. Readability - A noun and verb list and limit on sentence length that limits the manual to a fifth grade reading level.

2. Organization - A process of arranging the material in the book to reduce the need to shift from one part of the book to another while performing a continuing procedure.

3. Graphics/Text Correlations - This involves using pictures and graphic techniques that allow the novice to make a 'match' between what he sees in the manual and what he sees on the equipment.

While one would assume that the current maintenance documentation will do these things, it rarely does. In analyzing the maintenance actions requiring for the doppler radar system of the C-141, the Air Force found that the isolation and repair of one malfunction required reference to 165 pages of 8 documents[(2:10)].

The following table of experiments was extracted[(2:12)] showing the concepts used and results achieved.

In all of the experiments and field tests, inexperienced technicians performed better with fully proceduralized aids than with conventional documentation. Often, particularly when troubleshooting, the inexperienced technicians, even those who had attended the prescribed school, were unable to perform at all using conventional manuals. However, they were able to perform with minimal errors using the aids and their time to repair approached the time experienced technicians required when the latter used either conventional or experimental documentation.

To summarize some key findings of the studies:

- Repair time was reduced by up to 33 percent, with 80 percent fewer errors (BFIC) (2:13)
- As much as forty-two percent more malfunctions were found in 41 percent less time (MAINTRAIN) (2:12)

- Diagnosis time fell by as much as 67 percent (British Algorithm) (2:13)

- Training time was reduced as much as 60 percent for troubleshooting tasks and up to 100 percent for non-troubleshooting. (1:35)

- Inexperienced technicians using Job Performance Aids performed better than experienced technicians using traditional-type technical manuals (Non-Troubleshooting JPAs) (2:13).

TABLE III-1
Experimental Comparisons of Innovative Job Aids Versus Conventional Documentation

Concept	Year	Equipment	No. of Subjects	Results	Remarks
FORECAST	1958	Anti Aircraft Fire Control System	37	Equivalent performance	60% less training time
	1959	"	16	40% improvement in performance. stat. signif.	50% less training time
	1963	LORAN	98	Three times more faults identified. stat. signif.	Same training time
JOBTRAIN	1962	Comm. Equip.	39	Equiv. performance	50% less training time
MAINTRAIN	1963	NIKE AJAX Radar	16	42% more malfunction found in 41% less time	10% level of confidence was used
SYMPTOM-COLLECTION Manuals	1964	HAWK Radar	84	80% vs. 40% isolation of faults. stat. signif.	Experimental group was higher in aptitude
NIKE X MDS (A-VIS)	1964	Target tracking radar	15	Programmed material superior to conventional. Visual-only mode 27% more effective. Programmed TM 19% more effective. signif.	Results were a mixture of content and mode of presentation
SIMMS	1964	Radar	42	SIMMS gp. performed at 96%, controls at 70%	
	1971	SRC-20 Radio	178	Low trained grp. better with SIMMS high trained group better with conventional	Study was poorly designed and executed

Concept	Year	Equipment	No. of Subjects	Results	Remarks
BFIC	1966	Electronic Modules	80	Exper. group performed in 1/3 the time and made 1/5 the errors. Stat. signif.	High and low exper. and aptitude groups were matched
PIMO	1968	C141A	36	Apprentices performed non-troubleshooting tasks error free. Experienced technicians did troubleshooting in 11% less time and with 1/5 the errors. Stat. signif.	Only experienced technicians did troubleshooting
Fully Proced. Trouble-shooting JPA's	1968	Maintenance Task	61	High School students performed similar to exper. technicians	Dubious assumptions made to justify performance
British Algorithm	1969	Nav. Equip.	5	Ave. diagnosis time fell from 90 to 31 minutes	No statistical treatment reported
Non-trouble shooting JPA's	1970	F-4J	52	Inexper. technicians using guides performed 30% better than exper. using manuals Stat. signif.	Exper. personnel also did better than guides
Fully Proced. JPA's Maintenance Dependency Charts	1971	UH-1H Helicopter	90	USAF technicians better with JPA's than TM's. Apprentices better with JPA's than experienced technicians were with TM's. MDC's were inferior to JPA's and TM's. VNAF experienced technicians performed equally well with all aids, apprentices did better with JPA, outperforming experienced technicians.	Study not published No statistical significance indicated in summary. Original aids full of errors

Concept	Year	Equipment	No. of Subjects	Results	Remarks
SAFEGUARD MDS Phase four test	1972	Radar Return Generator	13	Technician performance not signif. diff. from test standards.	Procedure used to specify standards was questionable
Non-Trouble shooting JPA's	1972	Mobile electric power plant	26	Inexperienced made no more errors	JPA's had to be validated before test could proceed

SECTION IV

CONSIDERATIONS OF APPLYING THESE CONCEPTS
TO REDUCE LIFE CYCLE COSTS

The purpose of this section is to examine the effects of the total systems life cycle costs when the study results are applied. For the maximum savings to be realized, incorporation of these new training concepts must be planned for as early in a systems development as possible. The following graphic depicts the necessity to plan maintenance and training concepts early.

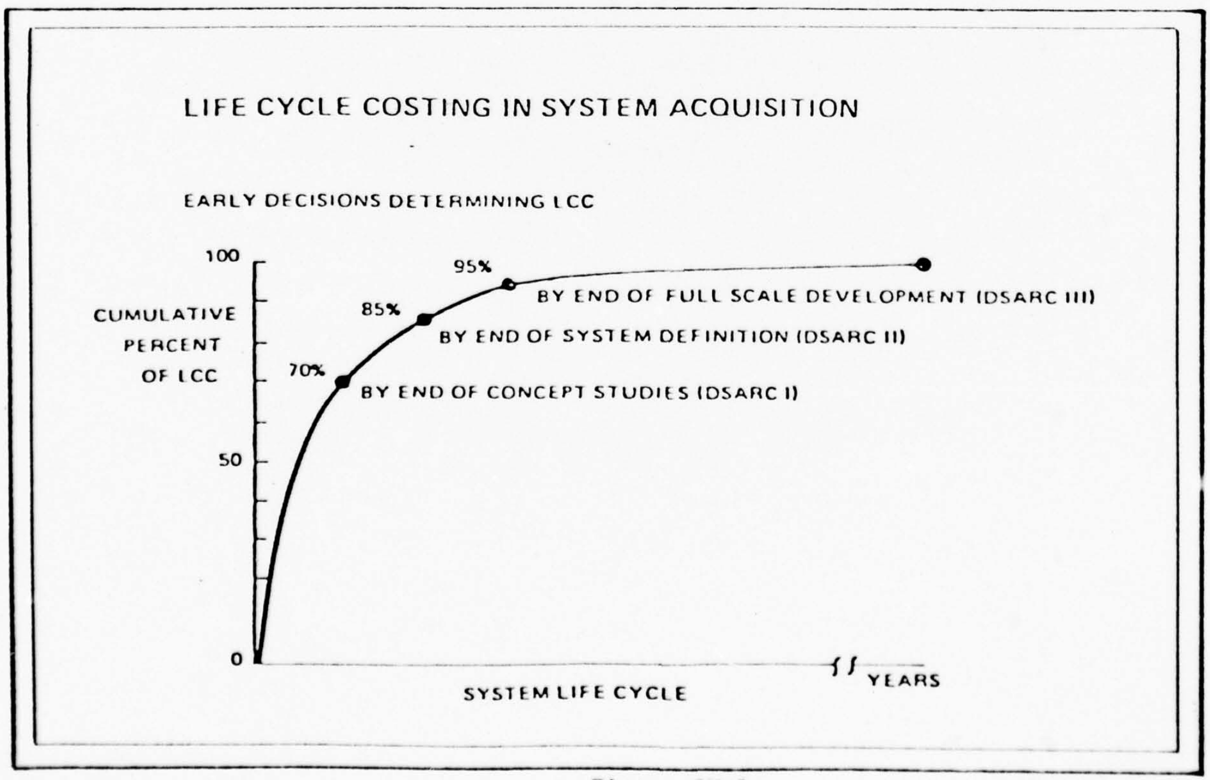


Figure IV-1

Many of the life cycle cost parameters are inherent in the design, however, the figure on the following page provides a close examination of the cost "DRIVERS" on one case[5].

Many Program Managers will undoubtedly feel that training and logistic support are either minor elements of their program or someone else's primary responsibility. For them the following is provided:

> QUOTE FROM DESIGN TO COST POLICY IN THE ARMY MATERIAL COMMAND GUIDE, DEC 74 AND INDORSED ON 3 JUL 74 IN A SECRETARY OF THE ARMY MEMORANDUM TO THE CHIEF OF STAFF, US ARMY. SUBJECT: DESIGN TO COST
>
> "Our ultimate objective is to minimize the total life cycle cost of ownership of a weapons system. . . . potential cost/performance trade offs and engineering changes must be evaluated in terms of their impact upon the overall cost of ownership of the system and appropriate weight should be given to this factor during source selection evaluation. Higher acquisition costs are acceptable provided that the additional investment will be amortized in a reasonable period of time through lower operating costs. However, designers should not be permitted to lower hardware acquisition costs to meet a design-to-cost goal if it would result in an uneconomical increase in operating and maintenance costs."

The systems of the future will be required to follow a design to cost philosophy. As human resources are a significant part of the life cycle costs of a system, to demand that systems be designed to human quality and quantity resource constraints from the very beginning is not only reasonable but necessary. The charts on figure IV-3 show growth curves that can be expected in developing hardware and documentation[6:23]. The scales of the chart are not the same. In fact a △○(output) on the documentation chart the same size as a △○ on the hardware chart is in fact 100 times as great in output. The △○ is the change in output.

ASSESSMENT OF LIFE CYCLE COST "DRIVERS"

ONE CASE

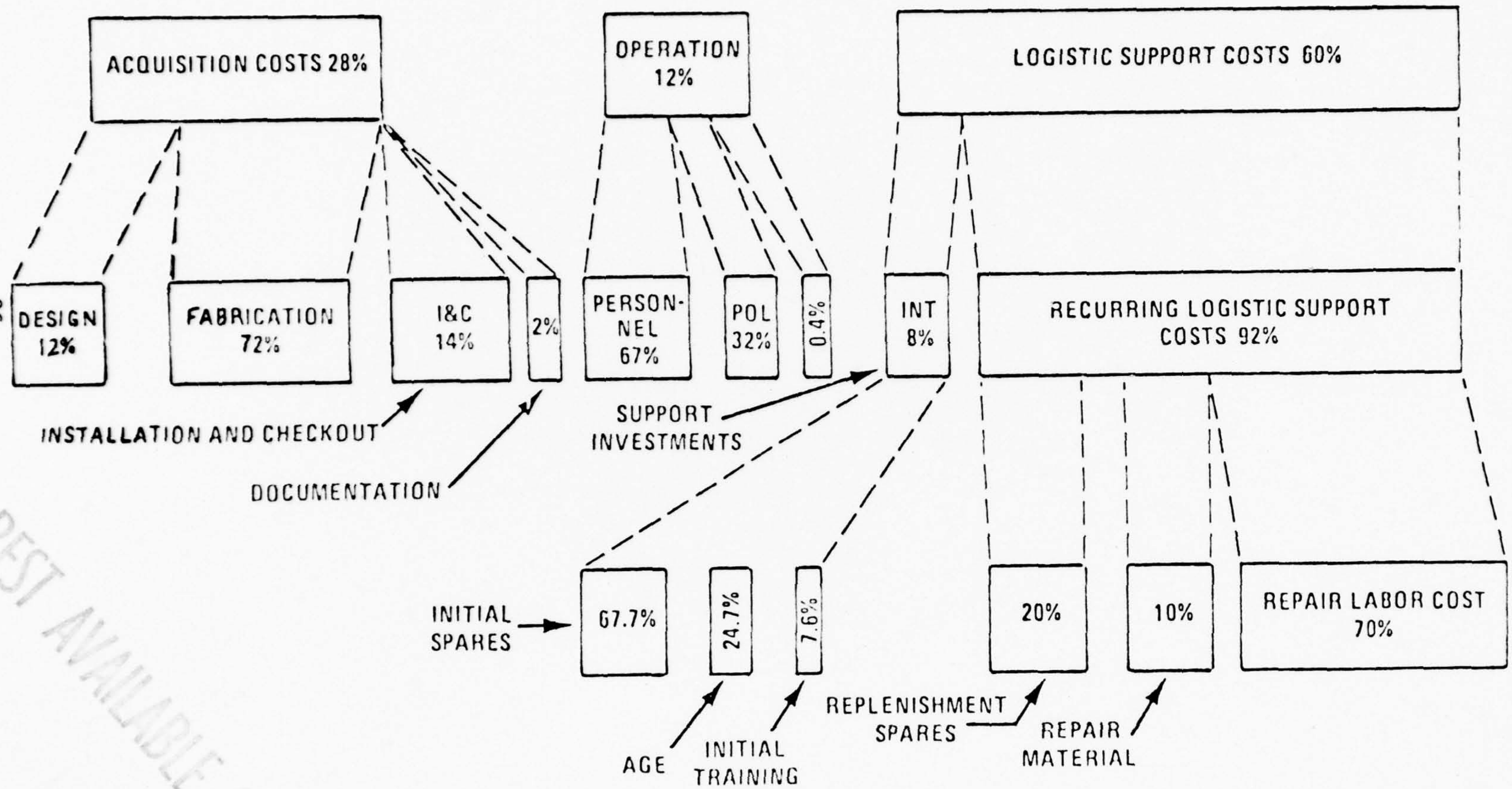
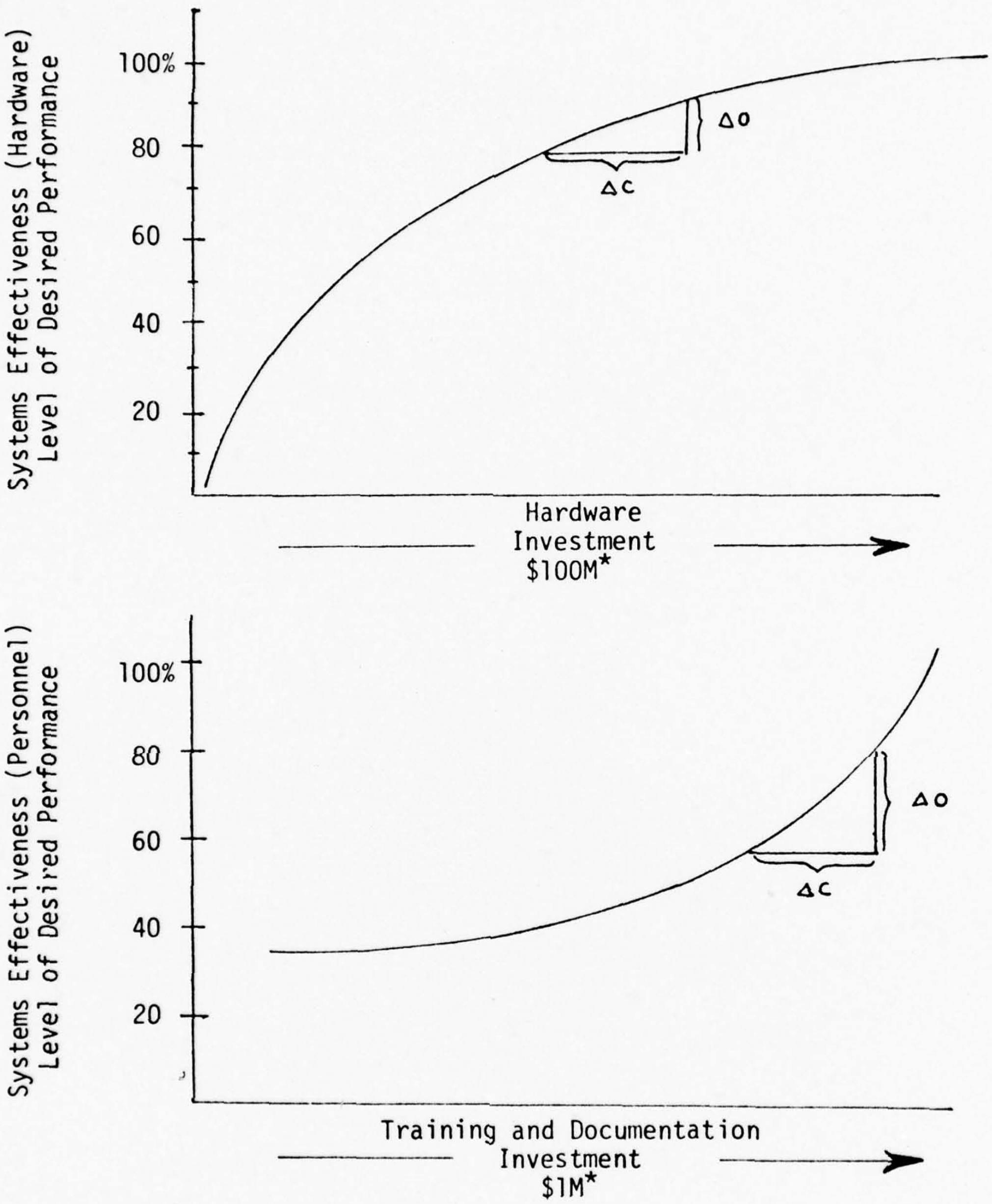


Figure IV-2



*Note the scale of the two curves is not the same. A $100K investment in training and documentation could be expected to provide considerably more performance increase in system effectiveness than the same investment in hardware.

Figure IV-3

The ΔC is the change in cost. Marginal Cost is $\frac{\Delta C}{\Delta O}$. The marginal benefit is the worth of the change in output. A fundamental proposition of economic analysis says "where resource constraints apply, optimal results are obtained when activities are carried to levels where they all yield the same marginal return per unit of effort or cost"[7]. Simply stated, you put your bucks into the system or activity that returns more for the buck until returns diminish. That is when the ratios of marginal benefits to marginal costs are equal at optimality[8]. By equation that would be:

$$\frac{MB_{HDW}}{MC_{HDW}} = \frac{MB_{T+D}}{MC_{T+D}}$$

MB_{HDW} = Marginal Benefit of Hardware

$MB_{T\&D}$ = Marginal Benefit of Training and Documentation

Most system acquisition programs are constrained by dollars, schedule, and performance. As money is invested over time, the performance parameters grow. Characteristically the hardware performance growth curve reaches a level where very little growth is realized even with extreme investments. The marginal return on the investment is very low. This portion of the curve is usually reached in the Full Scale Engineering Development Phase. Also, during this phase the technical documentation and the training aids must be developed and demonstrated. The management approach to getting the

greatest life cycle cost benefit is to invest the money in the portion of the program to provide the greatest marginal pay off, i.e., the greatest incremental return for the incremental investment. If improved training aids or technical documentation provide a greater expected LCC savings with a $1M investment than the same $1M investment in hardware reliability or maintainability improvement, then the investment should go into training aids and documentation.

Using a Life Cycle Cost model accessible by computer, this writer used the results of some of the earlier studies to determine expected savings. The model was exercised using a hypothetical but realistic electronic system under development. The model description, inputs and outputs are shown at Appendix A. All inputs were held constant except those treated as variables for this examination. They were:

Number of job skills (base case = 4)

Probability of false maintenance diagnostic[4:33] (30%)

Training time/cost (20 wks/$20K for Job Skill 1, $30K for Job Skill 2)

Retraining cycle (2-1/2 yr)

Mean time to repair (MTTR) (varied with task)

The study results used were:

a. Reduce MTTR 10%

b. Cut job skill requirements 50%

c. Reduce training time by 50%

d. Reduce false maintenance actions (parts replacements)

e. Examine a 5 year period between training.

The model was exercised after changing each variable. The results are summarized in Table IV-1. The computer printouts are at Appendix A. It is recognized that this exercise has been limited to a single model, however, the manpower and Life Cycle Cost reductions are so significant the results demand we can no longer afford to ignore the personnel subsystem.

The results indicate that a 10% reduction in mean time to repair (MTTR):

reduced the test equipment cost by 10%

reduced the manpower cost by 10%

reduced the training costs by 50%

reduced the Total Life Cycle Costs by 15.9%

A 50% reduction in the job skills further:

reduced manpower costs an additional 80%

reduced training costs an additional 30%

reduced the Total Life Cycle Costs an additional 36.5%

A lowering of the false part removal from 30% to 10% and reducing training time by 50% further:

reduced training costs an additional 50%

reduced Life Cycle Costs an additional 6.3%

With all other parameters held steady, the MTTR was varied from 90% to 80% to 70% resulting in:

reductions in test equipment cost by 11.27% and 12.7% respectively

reductions in manpower costs by 10.7% and 12.5% respectively

reductions of training costs by 10.7% and 10.5% respectively

reductions of Life Cycle Cost by 5.34% and 5.8% respectively

	BASE	ALT 1	ALT 2	ALT 3	ALT 4	ALT 5	ALT 6
Job Skills	4	4	2	2	4	4	4
Probability Removing False Part	30%	30%	30%	10%	10%	10%	10%
Training Time Factor	1.0	1	1	.5	.5	.5	.5
Retrain Cycle	2.5 yr	2.5	2.5	5	5	5	5
MTTR Factor	See App A	90%	90%	90%	90%	80%	70%
Cost of Selected Outputs (000)							
R&D	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Test Equipment	7%	71.	71.	71.	71.	63.	55.
Manpower	$\boxed{27,004}$	24,205	4,762	$\boxed{4,762}$	24,205	21,604	$\boxed{18,903}$
Training	15,144	6,785	4,702	2,351	3,393	3,029	2,650
Resulting Total LCC	$\boxed{70,183}$	59,010	37,484	$\boxed{35,133}$	55,617	52,645	$\boxed{49,558}$
Operational Availability	.9757	.9740	.9740	.9749	.9740	.9749	.9759

Table IV-1

Analysis of System Cost Parameters as Affected by Maintenance Training Variations

If all the benefits could be achieved as expected by the study results, the total life cycle costs could be reduced by approximately 50% (70,183 to 35,133). If only half the resulting benefit is realized, the results would still be a savings of 25% over the life of the system.

In addition to the cost savings available by improving training and technical documentation, other benefits can be postulated:

- job enrichment, hence higher expected reenlistment rate(7:21)
- fewer errors in the contractor produced documentation
- more utilization of men now in supervisory positions (presently 71% of inexperienced labor observes and assists) (2:48)
- fewer personnel moves as average stay on station for first termer is longer
- technicians leaving service should be better trained for production in civilian economy (2:47)
- improve reliability and operational readiness time
- reduce unscheduled maintenance manpower

Although a cost savings can be shown, the new techniques will certainly meet with opposition. One objection to acquiring documents with the new concepts has been that they cost more than conventional documentation and that project managers faced with competing requirements resist their adoption. If the cost savings potential is even a small fraction of what is claimed by proponents, the initial cost should not be an overriding factor. A budget quotation submitted to AFLC in 1971 for completion of flight line JPAs for the C-141 was $1,300,000 with troubleshooting aids and $800,000 without. McDonnell-Douglas reportedly estimated that JPAs

for the F-15 would cost $45 million versus $35 million for conventional documentation(2:50).

Most estimates indicate the cost at 100% to 125% of conventional documentation. In at least one case, cost estimates were less than the estimates for conventional manuals(2:50).

If new documents or JPAs were widely adopted, the production costs would probably come down due to the contractor learning and production techniques. Current JPA estimates from contractors accustomed to producing conventional manuals are probably inflated because of uncertainty. The industrial base for this kind of product would expand although fortunately there are currently at least a half dozen contractors who have demonstrated capability in this area.

SECTION V

CONCLUSIONS

The user is the program manager's customer. The whole purpose of system development or acquisition is to satisfy the user's need.

The service users have emphasized the need for technical and training documentation written for a lower reading level. The many studies conducted over the past two decades provide a means of satisfying this need and at the same time, reduce the manpower burden while improving the overall systems effectiveness, Figure V-1, which inherently provides lower life cycle cost (the current support costs are 50-55% of the total DoD budget).

Many decisions that affect the total life cycle cost of a system must be made while there are many unknowns in system design and manpower support requirements. Unfortunately it is in the early phases (conceptual and validation) of a program that manpower and training considerations must be weighed in selecting design and system alternatives. To delay the consideration of training and logistic support until full scale development will have drastic effects on life cycle costs as well as threatening the systems effectiveness due to a shortage of quality personnel. Since the user is the customer, he must participate in making trade-off decisions or provide the systems effectiveness parameters to enable the contractor to recommend trade-offs.

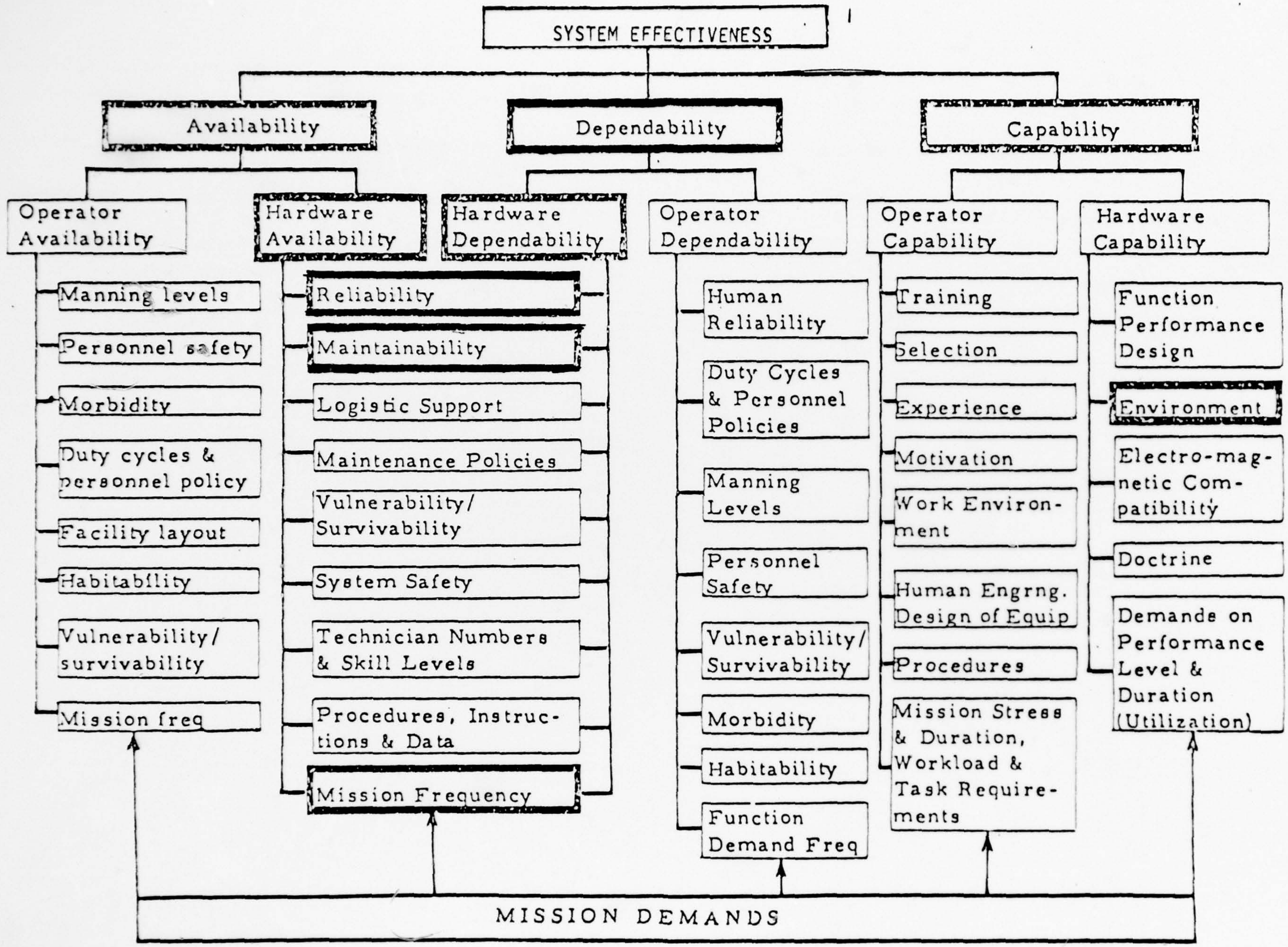

SYSTEM EFFECTIVENESS
Availability
Dependability
Capability
Operator Availability
Hardware Availability
Hardware Dependability
Operator Dependability
Operator Capability
Hardware Capability
Manning levels
Personnel safety
Morbidity
Duty cycles & personnel policy
Facility layout
Habitability
Vulnerability/ survivability
Mission freq
Reliability
Maintainability
Logistic Support
Maintenance Policies
Vulnerability/ Survivability
System Safety
Technician Numbers & Skill Levels
Procedures, Instructions & Data
Mission Frequency
Human Reliability
Duty Cycles & Personnel Policies
Manning Levels
Personnel Safety
Vulnerability/ Survivability
Morbidity
Habitability
Function Demand Freq
Training
Selection
Experience
Motivation
Work Environment
Human Engrng. Design of Equip
Procedures
Mission Stress & Duration, Workload & Task Requirements
Function Performance Design
Environment
Electro-magnetic Compatibility
Doctrine
Demande on Performance Level & Duration (Utilization)
MISSION DEMANDS

Figure V-1

A major problem is expected in getting this philosophy accepted and the training and technical documentation changes made. The institutional procedures don't change quickly. As long as Project/Program Managers emphasize Decision to Unit Production Cost at the expense of Life Cycle Cost the 'hardware fascination' will continue. The effect of the personnel subsystem, the personnel performing operations and maintenance, must be considered as the imperfect subsystem it is. Hardware design parameters should be modified upward accordingly to allow for the degradation due to imperfect personnel and yet meet the operational requirements as stated in the requirements document.

Life Cycle Costs are being emphasized in DoD 5000.28 and other DoD instructions, however, most implementers have difficulty getting a handle on the operations and support costs. The use of models such as the one used to support this study are available in each service[9]. They can provide sufficient data to support trade-off decisions in design, support equipment, manpower, and other resource limiting areas. To successfully use such models, information such as maintenance concepts, required operational and maintenance crews, types of maintenance tasks and the operational and logistic mission profile must be developed as inputs. In so doing the models will aid in design decisions[10]. The Life Cycle Costs developed by this analysis indicates that although absolute costs may not be available, relative merit can be determined by examining trade-offs, and forcing the contractor to concentrate on the system cost drivers.

It is also concluded that the improvement of training and technical documentation may be a totally new approach to cost savings as a viable alternative for satisfying new or upgraded requirements. Although a slight increase in development and procurement cost may be incurred by improving the documentation, the total life cycle costs should be reduced significantly (figure V-2)[11].

PAY OFF

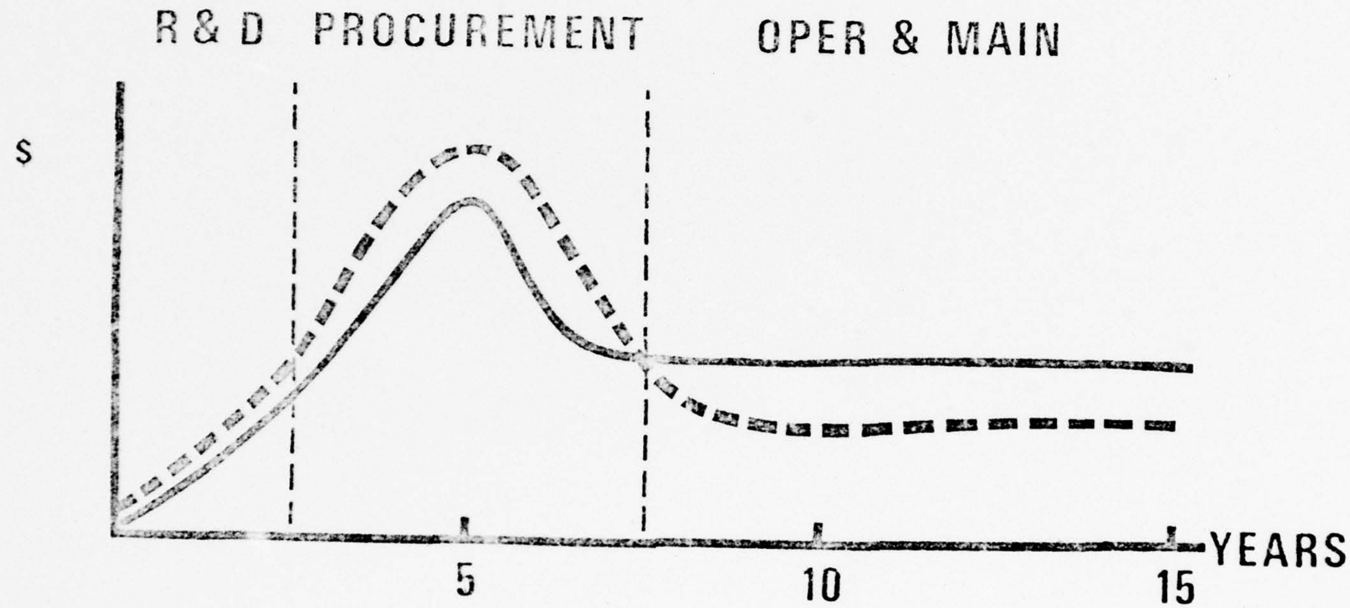


Figure V-2

RECOMMENDATIONS

RECOMMEND:

(1) That DoD direct each service to examine the possible life cycle cost savings, to each system undergoing Research and Development, as a result of using the documentation and training concepts developed by referenced studies and to implement those showing sufficient cost savings.

Realizing that documentation, training aids, and devices must be developed as components of each system, this writer recommends:

(2) Invest the Research and Development dollars in the areas where the expected marginal return is greatest. This requires acknowledging that the investment may legitimately be applied to improving a subsystem other than the hardware.

(3) That each new requirement document be examined for satisfaction of its requirement by the following priority methods:

- o New Job Performance Aids on existing equipment
- o Product Improvement to existing equipment
- o New System development

(4) That DoD schools dealing with systems acquisition take a more responsible role in teaching the development and contracting for improvement of high cost subsystems (other than hardware) such as personnel and logistic support. Also that the DoD schools be charged with assessing recommended methods to obtain Life Cycle Cost Savings and distribute promising methods to PM offices in each service.

IMPLICATIONS

The implication of this study is that DoD efforts to improve Life Cycle Costs is by emphasizing hardware cost improvement (i.e., Design to Unit Production Cost). This emphasis overlooks a very fruitful area that should provide higher payoffs. Any efforts to reduce Life Cycle Costs must be by early consideration of the improved concepts of operations and support and should be evaluated in view of the conclusions and recommendations of this study project.

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